Soil and water quality in a bottomland forest following hydrologic restoration

Katie Hossler and William J. Mitsch

Environmental Science Graduate Program, The Ohio State University

Abstract

In the spring of 2000, hydrology was restored to the Olentangy River Wetland Research Park (ORWRP) bottomland forest by breaching the levee separating the forest from the adjacent Olentangy River. Soil color and water quality parameters were measured in Fall 2003 for comparison with pre-restoration data. The percent soil chroma less than or equal to 2, increased from 46% (pre-restoration) to 70% at the 0 to 5 cm depth. Groundwater concentration of nitrate-nitrogen and orthophosphate also increased, with a significant difference between pre- and post-restoration nitrate levels ($p < 0.001$). The higher levels of nitrate and orthophosphate may indicate enhanced biogeochemical cycling due to the restored flooding regime.

Introduction

Joining upland with channel and upstream with downstream, bottomland forests are integral to ecosystem function. As water passes through a bottomland forest, nutrients are exchanged and transformed. Upstream inputs of inorganic nitrogen and phosphorus are filtered or exported downstream in organic form (Mitsch and Gosselink, 2000; Hinkle et al., 2001). Water from upland surface and groundwater flow becomes filtered of nitrate and phosphate in the riparian system before entering the river channel (Lowrance et al., 1984; Peterjohn and Correll, 1984; Lowrance, 1992; Hanson et al., 1994; Groffman et al., 1996; Verchot et al., 1997; Hefting and de Klein, 1998). Nitrate removal is thought to occur primarily through denitrification and plant assimilation (Lowrance, 1992; Hanson et al., 1994; Vought et al., 1995; Groffman et al., 1996; Correll, 1997; Verchot et al., 1997; Davidsson and Leonardson, 1998; Hefting and de Klein, 1998; Klapproth and Johnson, 2000; Groffman and Crawford, 2003), while phosphate retention occurs through deposition of particulate phosphorus and adsorption of dissolved phosphorus onto clay (Vought et al., 1995; Klapproth and Johnson, 2000). Without the buffering action of the riparian zone, non-point source overloading of nitrogen and phosphorus can result in eutrophication of the riverine system (Vought et al., 1995; Klapproth and Johnson, 2000).

To function properly, bottomland forests must remain open systems. An open system allows unimpeded nutrient flux between the riparian forest and surrounding ecosystems (NRC, 2002). Attendant flood pulsing from the river stimulates nutrient cycling in the riparian zone through alternate wetting and drying. The fluctuating moisture regime allows both aerobic and anaerobic processes (i.e., nitrification and denitrification) to occur which enhances biogeochemical cycling (Sánchez-Pérez and Trémolières, 1997; Davidsson and Leonardson, 1998; Takatert et al., 1999; Sánchez-Pérez and Trémolières, 2003). Construction of dams and levees and river channelization limit the openness of riparian systems with consequences for both riparian

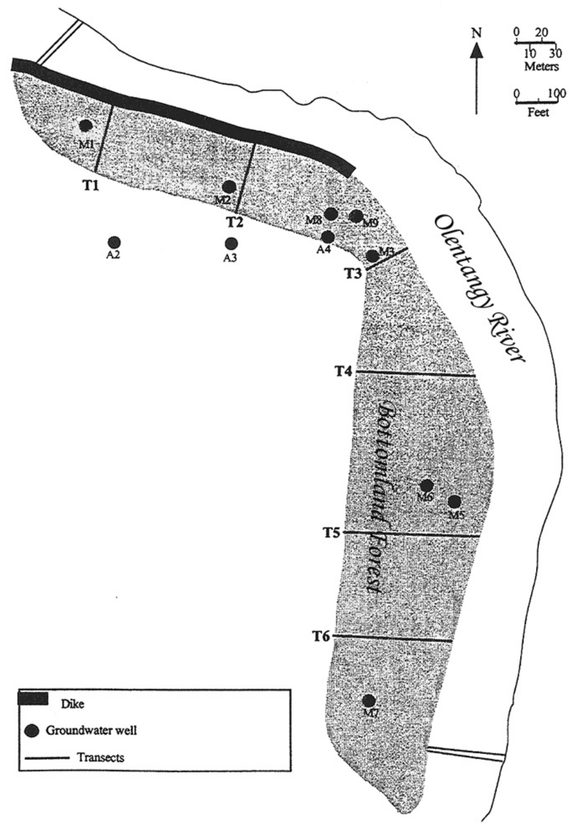

Figure 1. Map of the ORWRP bottomland forest with locations of soil transects and groundwater wells used in this study (adapted from Bouchard and Mitsch, 1999).

and riverine ecosystems (NRC, 2002; Sánchez-Pérez and Trémolières, 2003).

For over a century, the bottomland forest adjacent to the Olentangy River Wetland Research Park has been isolated from Olentangy River flooding by an artificial levee. In the spring of 2000, as part of a mitigation project, the levee was breached in four locations to help restore the forest's former hydrology. In this study, soil color and water quality were monitored in the bottomland forest and compared with data collected during a pre-restoration study of the bottomland forest (Bouchard and Mitsch, 1999).

Methods

Site description

The study was conducted in the 5.1-ha bottomland forest at the Olentangy River Wetland Research Park, located on the Ohio State University campus in Columbus, Ohio. The forest is bound on the north and east sides by the Olentangy River (Figure 1). Remnants of the artificial levee exist along the northern border. Prior to restoration, the bottomland forest would begin to flood only when the river stage exceeded the base of the levee (Acton et al., 1998). The breaching of the levee is expected to allow more surface water to flow into the wetland, although flood water may also drain more quickly (Acton et al., 1998).

Hydric soil status

Six transects were established across the bottomland forest, perpendicular to the Olentangy River (Bouchard and Mitsch, 1999; Figure 1). Soil cores were taken at 10 m intervals along each transect using a hand auger. The 0 to 5 cm and 5 to 10 cm core sections were compared to a Munsell Soil Color Chart and hue, value and chroma recorded.

Water quality

Water samples were collected on October 11, 19, 26 and November 5 of 2003, from the river and eleven groundwater wells (Figure 1). The first two sample volumes (250 mL) from each well were discarded to obtain a more representative sample. Dissolved oxygen (DO), pH, oxidation-reduction potential and temperature were measured on site with a YSI 6600 multiparameter probe. Five hundred mL samples were collected in polyethylene containers and stored (-4ºC) for later analysis of nitrate and orthophospate. For nitrate analysis, unfiltered water samples were preserved by acidification with 36 N H_2SO4. For orthophosphate analysis, water samples were filtered through 0.45 µm Millipore filterpaper (presoaked for 24 h

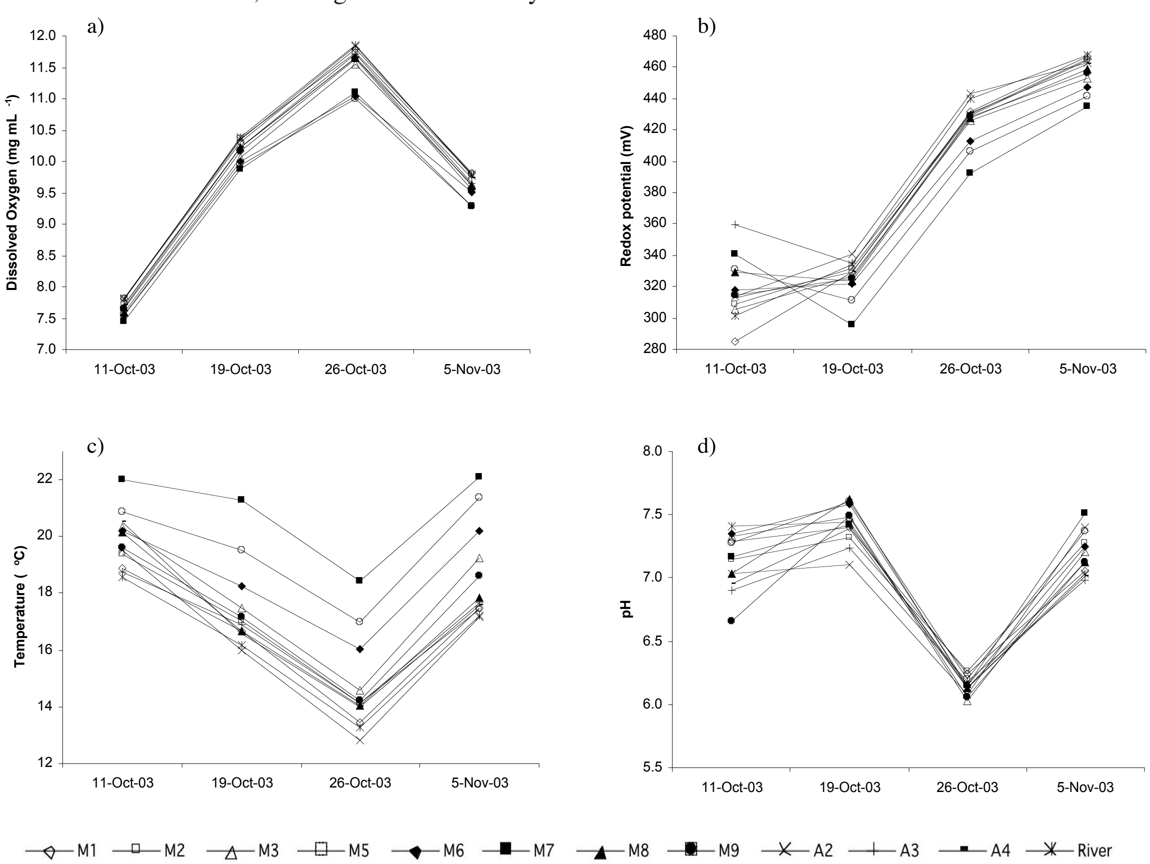

Figure 2. Water quality data collected from the groundwater wells and river, on October 11 through November 5, 2003: a) dissolved oxygen, b) redox potential, c) temperature, and d) pH.

Table 1. Comparison of soil chroma data collected in 1997, 1998, and 2003. Soil chromas less than or equal to 2 are considered hydric. Pre-restoration data were obtained from Geist (1998) and Bouchard and Mitsch (1999).

	Year	N	% Hydric	Median	Maximum	Minimum
0 to 5 cm	1998	28	46	2	4	2
	2003	37	70	3	3	1
5 to 10 cm	1997	15	13	2	6	2
	1998	28	43	3	5	2
	2003	37	70	3	3	1

in distilled water to remove contaminants). The prepared samples were analyzed on a Lachat QuickChem 8000 Series Flow Injection Analysis System.

Statistical analysis

Soil chroma data from this study were compared to pre-restoration data with the non-parametric Mann-Whitney U test. A two-sample t-test was used to compare nitrate and orthphosphate groundwater data to previous year data. All statistical analyses were performed with SYSTAT 10.

Results and Discussion

Hydric soil status

Seventy percent of the soil cores collected had a chroma of two or less, indicating hydric soil (Table 1; Appendix A). There were no observable differences between chromas at 0 to 5 cm and 5 to 10 cm depth. Significant differences in soil chromas (0 to 5 cm, $p = 0.026$; 5 to 10 cm, $p < 0.001$) were found between this year's study and two studies conducted prior to the bottomland restoration (Geist, 1998; Bouchard and Mitsch, 1999). At the 5 to 10 cm depth, 13% of the cores were reported hydric in 1997 and 43% in 1998 (Table 1). Additionally, the maximum and minimum chromas observed decreased at both depths from pre- to post-restoration (Table 1).

The observed differences may be an artifact of the hydric soil determination. The method of comparing a soil sample to a color chart is subjective and could be prone to personal bias. However, the differences might also be due to an increased presence of standing water over the 3.5 years since the levee breaching. Soil color has been found to change by one chroma unit within one year (Vespraskas et al., 1999). Pre- and post-development monitoring of the

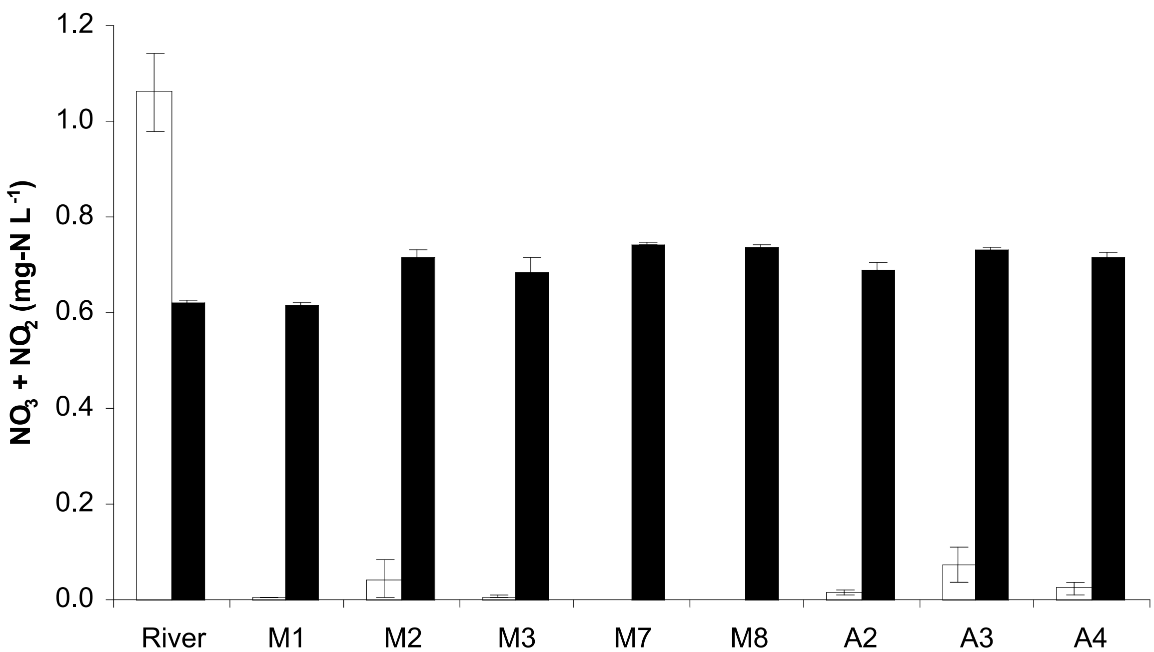

Figure 3. Comparison of nitrate-nitrogen means from this year (solid bars) and the pre-restoration study in 1998 (open bars; Bouchard and Mitsch, 1999). Error bars indicate standard error of the mean.

experimental wetlands at the ORWRP found consistently hydric chromas developed in the deepest parts within two years of flooding (Deshmukh and Mitsch, 2000). Hydric chroma development over four years was also observed for the ORWRP billabong, although the transition was slower and less complete due to the less frequent flooding regime (Gilbert et al., 1999; Broennum et. al., 2001).

Water quality

Figure 2 shows the water quality data for DO, redox-potential, temperature, and pH (see also Appendix B). The parameters fluctuated between sampling dates, but were similar among the groundwater wells and river. An increase in DO and redox-potential and decrease in pH and temperature on the third sampling date (October 26) were most likely due to a rain event. Only two samples had an oxidation-reduction potential less than 300 mV; denitrification begins to occur around 300 mV (Meek et al., 1969). However, results from the soil study suggest that anaerobic conditions do prevail in the bottomland, probably during wetter parts of the year such as late winter and spring (Vorbau et al., 1994).

Nitrate-nitrogen and orthophosphate values from this study and the pre-restoration study (Bouchard and Mitsch, 1999) are shown in Figures 3 and 4 (see also Appendix C). The groundwater nutrient levels were higher in 2003 than 1998, while the river nutrient levels were lower. The difference in groundwater nitrate was significant ($p < 0.001$). The results are similar to findings by Sánchez-Pérez and Trémolières (1997, 2003) who compared nitrate levels in two Rhine floodplains, one subject to periodic flooding and one remaining unflooded. Mean nitrate levels in the root zone were found to be higher in the flooded floodplain. The authors hypothesized that the higher nitrate concentrations in the flooded sector were due to alternate periods of aerobiosis and anaerobiosis occurring from water level fluctuation with flooding. When the water level was low, aerobic conditions prevailed and nitrification occurred. During high water, the nitrate produced under aerobiosis became solubilized, elevating the nitrate level in the groundwater. Groundwater nitrate was found to increase two to five times with flooding, with several weeks required for the nitrate concentration to return to normal low levels (Sánchez-Pérez and Trémolières, 1997). Consequently, while the nitrate level in the flooded floodplain was higher than the unflooded floodplain, the amount of nitrogen transformed was actually greater in the flooded floodplain.

A similar explanation may apply here. Approximately one week before the first sampling, the river stage at the Clinton Park weir was 221.18 m AMSL, which is high enough to flood portions of the bottomland forest. This flood event may be responsible for the elevated groundwater nitrate during the sample collection period. No similar high water event occurred during the 1998 sampling. Furthermore, phosphate levels were high initially and then declined over the 2003 sampling period (Figure 5); Sánchez-Pérez and Trémolières (1997, 2003) also observed phosphate to increase with flooding and to recover faster than nitrate. Phosphate concentrations can increase with flooding due to solubilization of sorbed phosphate minerals (Patrick and Khalid, 1974), floodwater input (Johnston, 1993), or biological process such as reduced biological demand (Mitsch and Gosselink, 2000; Wright et al., 2001) and microbial release of phosphate (Wright et al., 2001). The high phosphate concentration in the river suggests floodwater input was a significant source of groundwater phosphate (Figure 5). The observed patterns in both nitrate and phosphate groundwater concentrations support the Sánchez-Pérez and Trémolières hypothesis.

Qualitative removal of nitrogen in the bottomland forest is evident by examination of data from wells A3, A4, and M3 (Geist, 1998). The west to east well line runs perpendicular to potentiometric groundwater levels observed in previous studies (Vorbau et al., 1994; Voss and Merry, 1994; Vorbau, 1995; Acton et al., 1997). On the first two sampling dates, there is a decrease in nitrate from well A3 to well M3 (Figure 6). Nitrate levels are approximately the same for the last

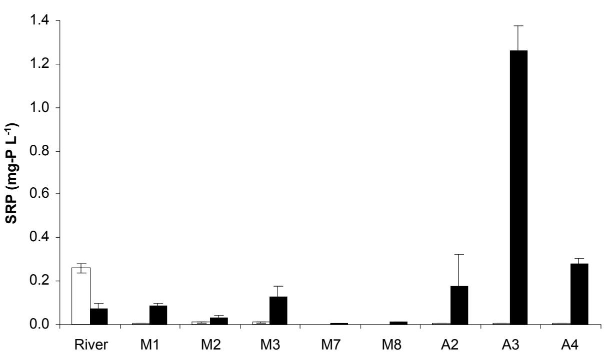

Figure 4. Comparison of soluble reactive phosphorus means from this year (solid bars) and the pre-restoration study in 1998 (open bars; Bouchard and Mitsch, 1999). Error bars indicate standard error of the mean.

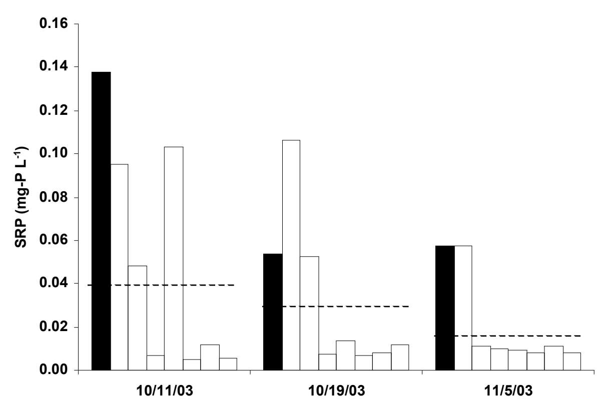

Figure 5. River (solid bars) and groundwater (open bars) phosphate levels from the first, second, and final sample dates. Dashed lines indicate groundwater means for each sampling session.

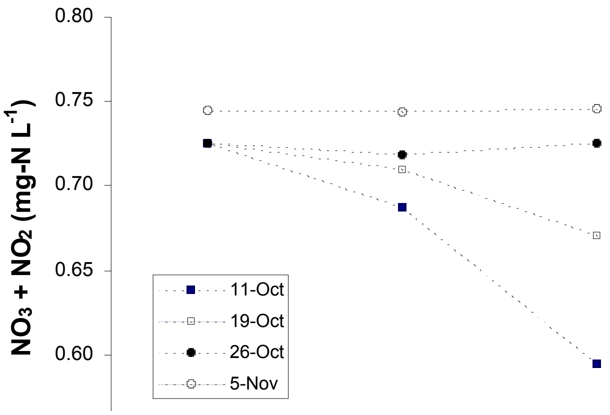

Figure 6. Nitrate concentrations along a groundwater flow line. The wells A3, A4, and M3 are oriented west to east along the flow line.

two sampling dates, which coincides with an increase in DO and redox-potential due to a rain event on the third sampling date (Figure 2).

Conclusion

The 24% increase in percent hydric soil (0 to 5 cm) from the 1998 study (Bouchard and Mitsch, 1999) indicates a positive change in bottomland forest hydrology following the levee breaching. Nitrate and phosphate data suggest that one outcome of the restored hydrology is an increase in nutrient cycling. A longer monitoring period, particularly in the spring and summer when microbial and plant activity is maximal, would be helpful in corroborating this observation.

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Appendix A. The values and chromas for the 0 to 10 cm soil cores collected in the bottomland forest. All cores had a hue of 10YR.

Transect	Value-Chroma								
1	3-2	3-2	4-3						
2	4-3	3-3	3-2	4-3					
3	4-3	4-2	3-3	3-2					
4	3-3	3-2	4-3	4-2	3-2	4-2	3-2	2-2	
5	4-3	3-3	4-2	4-2	3-2	3-2	3-2	2-2	3-3
6	4-2	4-2	4-2	3-2	4-2	3-2	3-2	2-2	4-1

Appendix B. Ground and river water quality data collected during fall 2003.

		11-Oct	19-Oct	26-Oct	5-Nov
pH	**M1**	7.29	7.40	6.24	7.05
	M2	7.15	7.32	6.26	7.28
	M3	7.33	7.48	6.03	7.21
	M5	7.28	7.60	6.20	7.37
	M6	7.35	7.58	6.15	7.25
	M7	7.17	7.42	6.15	7.51
	M8	7.03	7.62	6.13	7.13
	M9	6.66	7.49	6.06	7.13
	A2	7.03	7.11	6.08	7.40
	A3	6.90	7.24	6.18	6.98
	A4	6.95	7.39	6.13	7.01
	River	7.41	7.44	6.13	7.03
DO	**M1**	7.81	10.30	11.80	9.81
(mg mL^{-1})	**M2**	7.81	10.37	11.73	9.79
	M3	7.60	10.06	11.55	9.64
	M5	7.56	9.94	11.00	9.29
	M6	7.55	9.99	11.05	9.51
	M7	7.45	9.87	11.10	9.28
	M8	7.67	10.23	11.65	9.62
	M9	7.65	10.17	11.63	9.55
	A2	7.81	10.34	11.84	9.80
	A3	7.71	10.22	11.72	9.65
	A4	7.72	10.22	11.66	9.73
	River	7.79	10.39	11.86	9.78
Eh	**M1**	285.3	329.5	432.0	466.6
(mV)	**M2**	308.3	331.7	429.1	464.1
	M3	305.1	326.6	425.6	452.7
	M5	330.5	311.1	406.4	441.7
	M6	317.3	321.7	412.9	447.3
	M7	340.3	295.3	392.4	434.6
	M8	329.1	323.7	427.9	458.6
	M9	314.6	325.4	428.6	455.9
	A2	313.4	340.5	443.5	462.9
	A3	359.3	334.9	430.3	465.4
	A4	312.4	329.5	431.2	462.1
	River	301.4	334.0	440.0	467.5
Temp	**M1**	18.87	16.64	13.46	17.50
(^{o}C)	**M2**	19.40	17.01	14.13	17.43
	M3	20.35	17.49	14.59	19.26
	M5	20.88	19.51	16.97	21.39
	M6	20.18	18.23	16.02	20.20
	M7	21.99	21.27	18.45	22.10
	M8	20.17	16.64	14.04	17.84
	M9	19.60	17.14	14.23	18.63
	A2	19.51	15.99	12.82	17.18
	A3	18.76	16.91	14.14	17.65
	A4	20.49	16.58	13.97	17.56
	River	18.57	16.17	13.25	17.20

Appendix C. Nitrate and orthophosphate concentrations in ground and river water during fall 2003.

		10/11/03	10/19/03	10/26/03	11/5/03
$NO_3 + NO_2$ (mg-N L^{-1})	**M1**	0.603	0.618	0.635	0.607
	M2	0.670	0.725	0.725	0.745
	M3	0.594	0.670	0.725	0.745
	M5	0.603	0.618	0.659	0.609
	M6	0.745	0.744	0.745	0.744
	M7	0.744	0.744	0.745	0.745
	M8	0.724	0.744	0.744	0.744
	M9	0.725	0.745	0.745	0.744
	A2	0.692	0.677	0.667	0.725
	A3	0.725	0.725	0.725	0.744
	A4	0.687	0.709	0.718	0.743
	River	0.612	0.625	0.633	0.609
SRP (mg-P L^{-1})	**M1**	0.0951	0.106	0.0890	0.0576
	M2	0.0482	0.0525	0.00935	0.0112
	M3	0.0680	0.229	0.195	0.0115
	M5	0.00682	0.00739	0.00688	0.0101
	M6	0.103	0.0138	0.00645	0.00921
	M7	0.00480	0.00700	0.00883	0.00773
	M8	0.0120	0.00813	0.00994	0.0110
	M9	0.00567	0.0118	0.00956	0.00784
	A2	0.608	0.0170	0.00982	0.0706
	A3	4.54	0.439	0.0318	0.0239
	A4	0.0800	1.03	0.0111	0.00726
	River	0.138	0.0538	0.0460	0.0577